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SPECIFICATION

1. Title of the Invention: JOYSTICK

2. Claim

A joystick comprising:

a ball coupled to an operational lever, having a built-in permanent magnet;

a ball receptor for supporting said ball with a precession-freely; and

two pairs of magnetic sensors being built-in said ball receptor and perpendicularly intersecting each other,

a gradient direction and a size of said operational lever being decomposed into quadrature components by a rotational magnetic field of the permanent magnet, and output by said pairs of magnetic sensors,

wherein each of said magnetic sensors outputs a sinusoidal wave output whose phase differs from said rotational magnetic field of said permanent magnet with a 1/4 wavelength, and signal processes these outputs with an arithmetic circuit such that these outputs are linearized by performing an operation of an arithmetic on these outputs per 1/4 wavelength.

3. Detailed Description of the Invention

This invention relates to a non-contact type joystick with the purposes of an expansion of a detection angle range and an improvement of detection accuracy.

A joystick having an ability of controlling a device by decomposing a gradient direction and a size of an operational

lever into quadrature components and electrically outputting is applied to the variety of fields such as a cursor control of a CRT display, a remote control of an industrial robot, a control lever of a television game, etc. For this joystick, there is a contact type joystick of which fixed transducers are disposed in X and Y directions which are two directions perpendicularly intersecting each other and a displacement angle component of the operational lever is decomposed into the rotational angles of the axes of two fixed transducers and then fetched, but for this contact type joystick, it can not expect to have a smooth operation thereof because of a complexity of a mechanism, and also there is a problem of a short lifetime caused by a wear-out, so that at the present time, it has a tendency to adopt many of a non-contact type joystick which combines a permanent magnet and a magnetic sensor for an angle detection, which will be described in the following.

With reference to Figs. 1 and 2, by describing one example of this non-contact type joystick, (1) refers to an operational lever, (2) refers to a ball of non-magnetic material which is fixed at one end of the operational lever (1), (3) refers to a cylindrical permanent magnet with axially magnetized, which is embedded inside the ball (2), and the operational lever (1) and the permanent magnet (3) share a center line which passes through a center of the ball (2). (4) refers to a ball receptor for supporting the ball (2) with a freely-precession, (5) and (6) refer to two magnetic sensors embedded into the ball receptor (4), and they are, for example, magnetoresistance elements (hereinafter, refers to as MR elements) of which a resistance value thereof varies with a directional change of a magnetic field. These respective MR elements (5), (6) are, for example, as shown in Fig. 3, such that two stripes (8a), (8b) of ferromagnetic metal thin films perpendicularly intersecting each other are deposited on an insulating substrate (7), and by applying a bias voltage

V0 to both terminals (9a), (9b) of these stripes (8a), (8b), and by demanding an output V from a mid-terminal (9c), $V=kV_0\sin 2\theta$ is then obtained. Herein, k is a constant inherent to a material, and theta is an angle of an external magnetic field H observed from a direction P which forms 45° with the stripes (8a), (8b).

These two MR elements (5), (6) are disposed toward the center point of the ball (2) near the ball (2) and toward the X and Y directions which are two directions perpendicularly intersecting each other, and as a result of this, with the outputs of the two MR elements (5), (6), the gradient direction and the size of the operational lever (1) are decomposed into the X-Y quadrature components and then detected. That is, now considering the X, Y, and Z axes as shown in Fig. 4, disposing the respective MR elements (5), (6) on the XZ plane and the YZ plane as the magnetosensitive surfaces thereof being in parallel, and assuming that the magnetic field H of the permanent magnet (3) matching with the direction of the operational lever (1) is situated in a position where is rotated in an angle θ from the X axis, and the magnetic field H is situated in a position where is inclined in an angle φ from the Z axis. Then, at this moment, the projection angles θx, θy of the magnetic field H to the respective MR elements (5), (6) are represented as

$$\theta x = \tan^{-1} (\tan\varphi \cdot \cos\theta)$$

$$\theta y = \tan^{-1} (\tan\varphi \cdot \sin\theta).$$

Accordingly, the outputs Vx, Vy of the respective MR elements (5) (6) become as

$$Vx = k\ V_0 \sin 2\theta x \quad \ldots(1)$$

$$Vy = k\ V_0 \sin 2\theta y \quad \ldots(2).$$

These equations (1) and (2) can be approximated as

$$Vx = 2k\ V_0 \tan\varphi \cdot \cos\theta \quad \ldots(3)$$

$$Vy = 2k\ V_0 \tan\varphi \cdot \sin\theta \quad \ldots(4)$$

assuming a case that the φ is sufficiently small. Therefore, from these equations (3) and (4), the rotational angle θ and the

inclination angleφ can be obtained by an arithmetic with the following equations.

$$\theta = \tan^{-1}\frac{V_y}{V_x} \qquad \ldots (5)$$

$$\varphi = \tan^{-1}\sqrt{\frac{V_x 2 + V_y 2}{2kV_0}} \qquad \ldots (6)$$

However, as can be seen from the equations (1) and (2), because that the outputs of the respective MR elements (5), (6) are sinusoidal wave outputs, the θ and the φ are both non-linear, and thus there existed a problem that a detection range of a high accuracy would become narrower. In fact, the equations (5) and (6) are approximation equations which can be established only when theφ is sufficiently small, and the error would have been larger as theφ becomes larger. For example, Fig. 5 shows the results of which the maximum errors max $\delta\varphi$ and max$\delta\theta$ of the errors$\delta\varphi$ = $\varphi_0-\varphi$, $\delta\theta=\theta_0-\theta$ between the inclination angleφ, the rotational angle of θ the operational lever (1) computed as described above and the actual inclination angleφ_0, the actual rotational angleθ_0 are checked by varying theφ. As can be seen from the figure, both of the maximum errors max$\delta\varphi$ and max$\delta\theta$ reach to 1 degree by inclining the inclination angleφ of the operational lever (1) to an amount of 15°, and then further increasing theφ, it has a tendency to increase rapidly. As described above, an application to the various kinds of fields has been difficult for a conventional joystick, since a usage range is limited to a narrow range, from the detection accuracy viewpoint.

Accordingly, the present invention has been made in the view of the problems described above, and provides a non-contact type joystick which is capable of expanding a detection range as large

as possible, without reducing a detection accuracy.

The joystick according to the present invention is characterized in that, two magnetic sensors from which the two sinusoidal wave outputs whose respective phases to the magnetic field direction differ by a 1/4 wavelength are extracted, are placed on the surfaces perpendicularly intersecting each other within the magnetic field space provided from the permanent magnet fixed on the operational lever. Then, the detection outputs of the respective two sinusoidal waves of these magnetic sensors are processed by an electrical circuit with which they are summed and subtracted per a 1/4 wavelength range, respectively, thereby the linearized arithmetic outputs are obtained.
Accordingly, the non-linear sinusoidal wave detection outputs of the respective magnetic sensors are extracted as the linearized arithmetic outputs, and an expansion of the detection range can be planned without reducing the detection accuracy.

In the following, an embodiment of the present invention will be described in detail with reference to the accompanying drawings. In Figs. 6 and 7, the same reference numbers represent the same elements as in Figs. 1 and 2, thus the details thereof are omitted. In the present invention, the things which are different from the conventional ones are the following two MR elements (10) (11) and the arithmetic circuits (12) (13). That is, the two MR elements (10) (11) are placed in the same positions as the conventional MR elements (5) (6), and the configurations thereof differ as follows. Now, describing the one MR element (10) placed in the X direction, as shown in Fig.8, it is such that four ferromagnetic metal thin film stripes (15a) (15b) (15c) (15d) are formed on an insulating substrate (14), and two adjacent stripes (15a) (15b) are perpendicularly intersecting each other in sequence, and output an output V1 from the detection terminal φ_1 of the middle point thereof. Further, the remaining stripes (15c) (15d) are also perpendicularly intersecting each other,

and output an output V2 from the detection terminal of the middle point thereof. Moreover, these two pairs of stripes (15a) (15b) and (15c) (15d) have the angle of 45 ° each other, both ends of the respective pairs are connected, and a common bias voltage V0 is applied from the current terminals φA, φ B of these both ends. The MR element (10) with the structure as described above is that the MR element (16) of a three-terminal structure having the MR stripes (15a) (15b) of the pattern, perpendicularly intersecting each other, and the MR element (17) of a three-terminal structure, being respectively inclined in 45 ° with the pattern, having the MR stripes (15c) (15d) of the pattern, perpendicularly intersecting each other are such that φA, φ B are respectively made to be as the common power supply terminals, and each of the elements (16) (17) can be formed independently. Then, but not shown, the respective MR elements (16) (17) are corresponding to the respective MR stripes (15a) (15b) (15c) (15d) and bridge-connected to two fixed resistors and differentially amplified, then output the detection voltages V1, V2, respectively. That is, when the magnetic field H is provided to the MR element (10) in the angle φx with respect to the reference direction P, then the outputs V1, V2 shown in the next equations are outputted.

$$V1 = k\ V_0 \cos 2\theta x$$

$$V2 = k\ V_0 \sin 2\theta x$$

That is, V1 and V2 are sinusoidal wave outputs whose phases differ in a 1/4 wavelength and it becomes the graph shown with the solid line in Fig. 9 when being plotted. However, the sinusoidal wave outputs V1, V2 such as the ones differing in a 1/4 wavelength are consisted of the convex shape portion A and the concave shape portion B which are gradually increasing and gradually decreasing, respectively. Therefore, as summing these convex and concave parts A, B by aligning both of these with the direction of either gradually increasing or gradually decreasing, and then as shown

in the dotted line, each of the concave part and the convex part is averaged, and thus linearized outputs are obtained. Also, since these linearized outputs have respectively the same inclination at the respective wavelength ranges, the linearized arithmetic outputs would be obtained over the complete wavelength ranges by appropriately biasing them. Thus, calculating both of these outputs V1, V2 in the arithmetic circuit (12) per a 1/4 wavelength with the following equation (7).

$$
\begin{aligned}
Vx1 &= -V1+V2-3V0, \quad (0 \le \theta \le 45°) \\
Vx2 &= -V1-V2-V0, \quad (45° \le \theta \le 90°) \qquad \ldots(7) \\
Vx3 &= V1 - V2 + V0, \quad (90° \le \theta \le 135°) \\
Vx4 &= V1 + V2 + 3V0, \quad (135° \le \theta \le 180°)
\end{aligned}
$$

That is, the term (-V1+V2) (-V1-V2) (V1-V2) (V1+V2) of the respective arithmetic equations of the outputs Vx1, Vx2, Vx3, Vx4 per a 1/6 wavelength of the output V of the arithmetic circuit (12) are linearization equations, and by selectively summing and/or subtracting -3V0, V0, +V0, +3V0 to these ones, then the output Vx is linearized with respect to the inputθx as shown in the lines 11, 12 of Fig. 8.

The electrical circuit can easily perform the arithmetic such as above, for example, such as shown in Fig. 10. That is, (18) (19) (20) (21) are the inverter circuits, (22) (23) are comparator circuits, (24) is a descriminator circuit, (25) (26) are multiplexers, and (27) is an adder circuit. +V1 and +V2, as well as -V1 and -V2 which are inverted by the two inverter circuits (18) (19) are inputted to one (26) of the multiplexers, and +V0 and +3V0, as well as -V0 and -3V0 which are inverted by the two inverter circuits (20) (21) are inputted to the other multiplexer (26). The two (22) (23) of the comparator circuits compare whether V1 and V2 are positive or negative and output the result of comparison to the discrimination circuit (24), and the discrimination circuit (24) discriminates such that V1 and V2 are in the range of $0 \le \theta \le 45°$ when both of V1 and V2 are positive,

in the range of $45° \leq \theta \leq 90°$ when V1 is negative and V2 is positive, in the range of $90° \leq \theta \leq 135°$ when V1 and V2 are both negative, and in the range of $135° \leq \theta \leq 180°$ whenV1 is positive and V2 is negative. Then, the descriminator circuit (24) sends the discriminated result to the multiplexers (25) (26). As a result, the multiplexers (25) (26) select only the ones of the respective items ±V1, ±V2, ±V0, ±3 V0 to be calculated, based on a discrimination signal of the descriminator circuit (24) and then send the calculated result to the adder circuit (27). The adder circuit (27) computes either one of the equation (7), thereby the output Vx is obtained. The arithmetic circuit (12) described as above can be achieved by a circuit configuration which is a relatively simple and an inexpensive since the summing and subtracting are the main contents thereof.

Also, the MR element (11) placed in the Y direction and the arithmetic circuit (13) thereof have the same contents as the above-mentioned MR element (10) and the arithmetic circuit (12). That is, the MR element (11) outputs two outputs $V3 = k V_0 \cos 2\theta y$, $V4 = k V_0 \sin 2\theta y$, and the arithmetic circuit (13) computes a linearized output Vy from these two outputs V3, V4.

Now, as shown in Fig. 4, by letting θ to be a rotational angle with respect to the Z axis, of the operational lever (1), and θx, θy to be projection angles of the magnetic field H to the respective MR element (10) (11), then as the same as the conventional one they are represented by

$$\theta x = \tan^{-1} (\tan\varphi \cdot \cos\theta)$$

$$\theta y = \tan^{-1} (\tan\varphi \cdot \sin\theta)$$

thus the outputs Vx, Vy of the respective arithmetic circuits (12) (13) are obtained as the linear relation equations,

$$Vx = k V_0 \theta x \qquad \ldots(8)$$

$$Vy = k V_0 \theta y \qquad \ldots(9)$$

and the rotational angle θ and the inclination angle φ are obtained as follows.

$$\theta = \tan^{-1}\left(\frac{\tan\frac{V_y}{V_0}}{\tan\frac{V_x}{V_0}}\right) \qquad \ldots (10)$$

$$\varphi = \tan^{-1}\sqrt{\tan^2\frac{V_x}{V_0} + \tan^2\frac{V_y}{V_0}} \qquad \ldots (11)$$

The rotational angle θ and the inclination angle φ of the operational lever (1) obtained as described above are, for the respective MR elements (10) (11), the detection output V1, V2 of the non-linear sinusoidal waves whose phases differ a 1/4 wavelength respectively for the inputs of the magnetic field angle of the permanent magnet (3), but by processing the above calculations, the linearized arithmetic outputs which are proportional to the magnetic angle as shown in the equations (8) and (9) are obtained.

As described above, according to the present invention, the linearized outputs corresponding to the rotational angle and the inclination angle of the operational lever have been obtained and the detection accuracy has been enhanced, and also the angle detection range is greatly expanded. In fact, on the contrary to that the conventional effective use angle is just ±15 °, the effective use angle range is expanded to ±90 ° for the present invention, and thus the effectiveness has been demonstrated.

Further, the joystick structure of the present invention is not intended to limit to the embodiments described as above, and, for example, an idea of arranging that the ball is made to be as a hollow and the magnetic sensors are fixedly placed therein, etc. is also possible. Moreover, although the magnetic sensors are placed on the orthogonal surfaces adjacent each other within

the magnetic field space of the magnet, it is possible to place them on the four surfaces opposite each other.

4. Brief Description of the Drawings

Figs. 1 and 2 are respectively a side cross sectional view and a cross sectional view along the line II-II of the conventional joystick, Fig. 3 is a main unit plane view showing one example of the MR element, Fig. 4 is an operation principle diagram for illustrating the detection principle of the rotational angle and the inclination angle of the operational lever in the joystick, Fig. 5 is an error characteristic diagram of Fig. 1, Figs. 6 and 7 are respectively a side cross sectional view and a cross sectional view along the line VII-VII of the mechanism unit showing one embodiment of the present invention, Fig. 8 is a main unit plane view showing one example of the MR element (the magnetic sensor) used for the present invention, Fig. 9 is a waveform diagram of the outputs of the MR element and the arithmetic outputs of Fig. 8, and Fig. 10 is a block diagram showing one example of the arithmetic circuit of Fig. 7.

(1)...operational lever, (2)...ball, (3)...permanent magnet, (4) ...ball receptor, (10) (11) ...magnetic sensors (MR elements), and (12) (13) ...arithmetic circuits.